WHERE SCIENCE AND POLICY MEET

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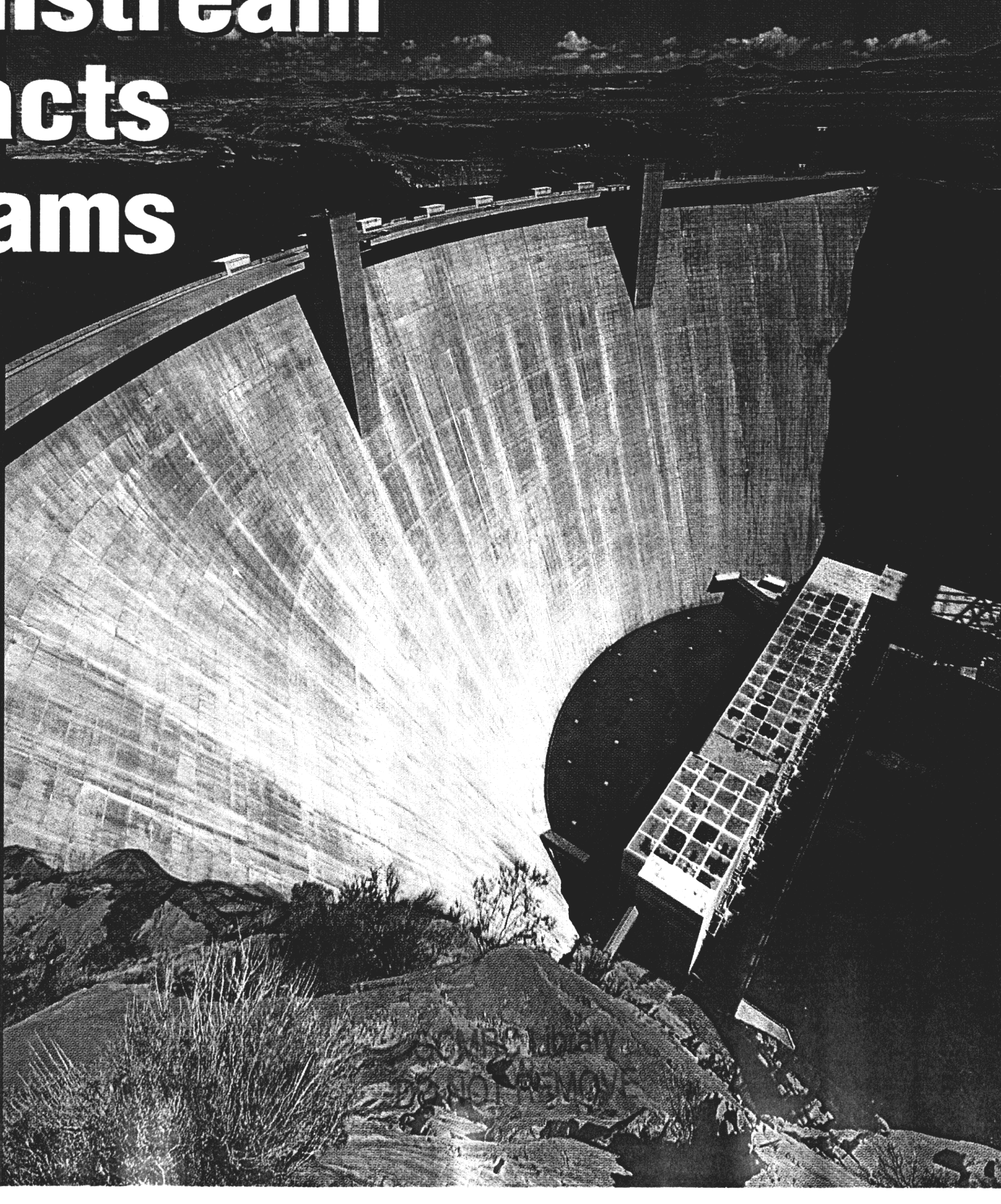
Downstream Impacts of Dams



ALSO . . .

Soil degradation in Africa's Sahel

European advances in transboundary pollution

Adaptive Management, Heal Thyself

Adaptive environmental management is an idea whose time ought to have come. Its core ideas were articulated nearly a quarter century ago by Canadian ecologist C. S. Holling and his colleagues. Adaptive management was put forward as a strategic alternative to the static checklists, overly ambitious computer models, and separation of research and operations that then increasingly characterized environmental management. It argued that the complex, nonlinear, multi-scalar character of ecosystems rendered their behavior under management ultimately unpredictable. Efforts to lay down fixed blueprints for managing environmental resources were therefore futile. In their place, Holling and his colleagues advocated a strategy of improving management through systematic efforts to learn from the results of operational management experience.

At one level, the original adaptive management ideas reflected little more than an acknowledgement that ecosystem science was not yet up to the task of fully replacing trial-and-error practice or "muddling through" as a guide for the management of complex ecosystems. In its more developed and most aggressive forms, however, adaptive management advocates treating management policies as experiments, which are then designed to maximize learning rather than only immediate resource yields. This view emphasizes the need to formulate management policies as refutable hypotheses about how ecosystems respond to human intervention, to design monitoring systems that can provide reliable data about the results of management experiments and, above all, to construct management institutions and processes that are able to learn from their failures.

Over the last two decades, the idea of adaptive management has generated a growing literature, much of it accessible through the web and, particularly, in the on-line journal *Conservation Ecology* (http://www.consecol.org). The idea has been applied throughout the world to an increasing range of environmental management problems. These include international efforts to protect the stratospheric ozone layer, transboundary conservation programs for the Pacific salmon, Australian river basin initiatives, and Canadian work in forest management. In the United States, adaptive management strategies for ecosystem restoration have been adopted for places as different as the Everglades, the San Francisco Bay, and the Grand Canyon. Elements of the Grand Canyon experience are reviewed by Jeffrey W. Jacobs and James L. Wescoat Jr. in their article that begins on page 8.

Much good has surely been accomplished in the name of adaptive management. But there seems little doubt or debate that the idea—while raising important issues—has yet to fulfill its promise in practice. There are many reasons for this, not least the complexity of the linked ecological and social systems that adaptive management seeks to address and the high political stakes involved in the outcomes it seeks to influence. As Jacobs and Wescoat point out, another factor contributing to the underperformance of adaptive management ideas almost certainly involves the institutions through which those ideas would have to be implemented and in which the lessons of policy success and failure would have to be learned. Most institutions are not very good at learning, especially when such learning would entail significant revision of their own goals and operating procedures. Environmental management institutions are no better than the norm and may be significantly worse—a point emphasized by *Environment*'s former executive editor Gilbert F. White in his recurrent lament on the absence of post-audits of water resource policies. Realizing the potential of adaptive environmental management will likely require, as Jacobs and Wescoat argue, that we complement our substantial research on how ecosystems respond to management with comparable efforts to understand how management systems can learn from and adapt to their own inevitable errors.

—William C. Clark

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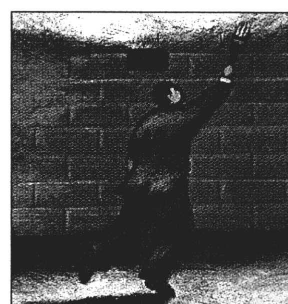
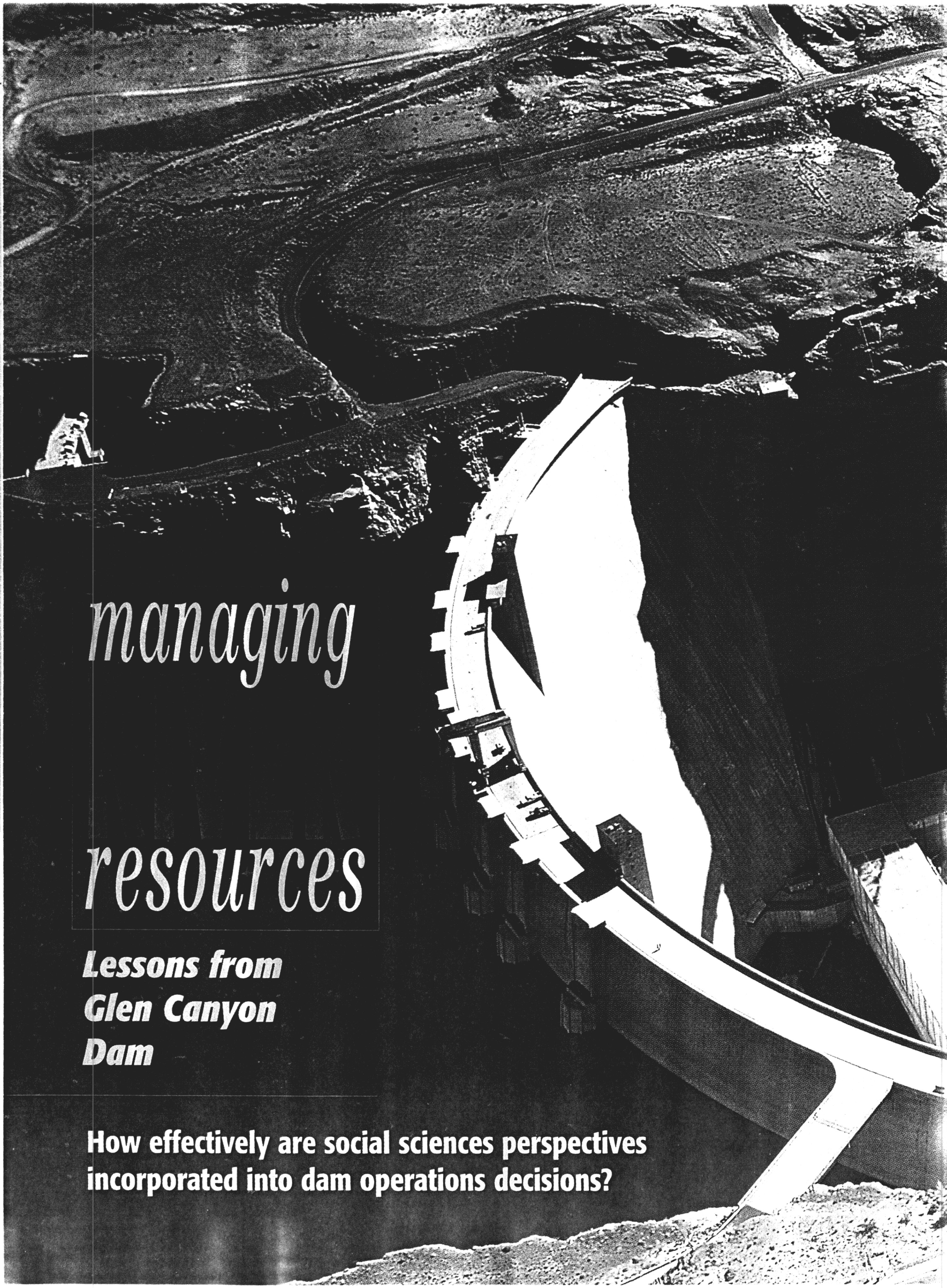
ARTICLES



DEPARTMENTS

ABOUT THE COVER

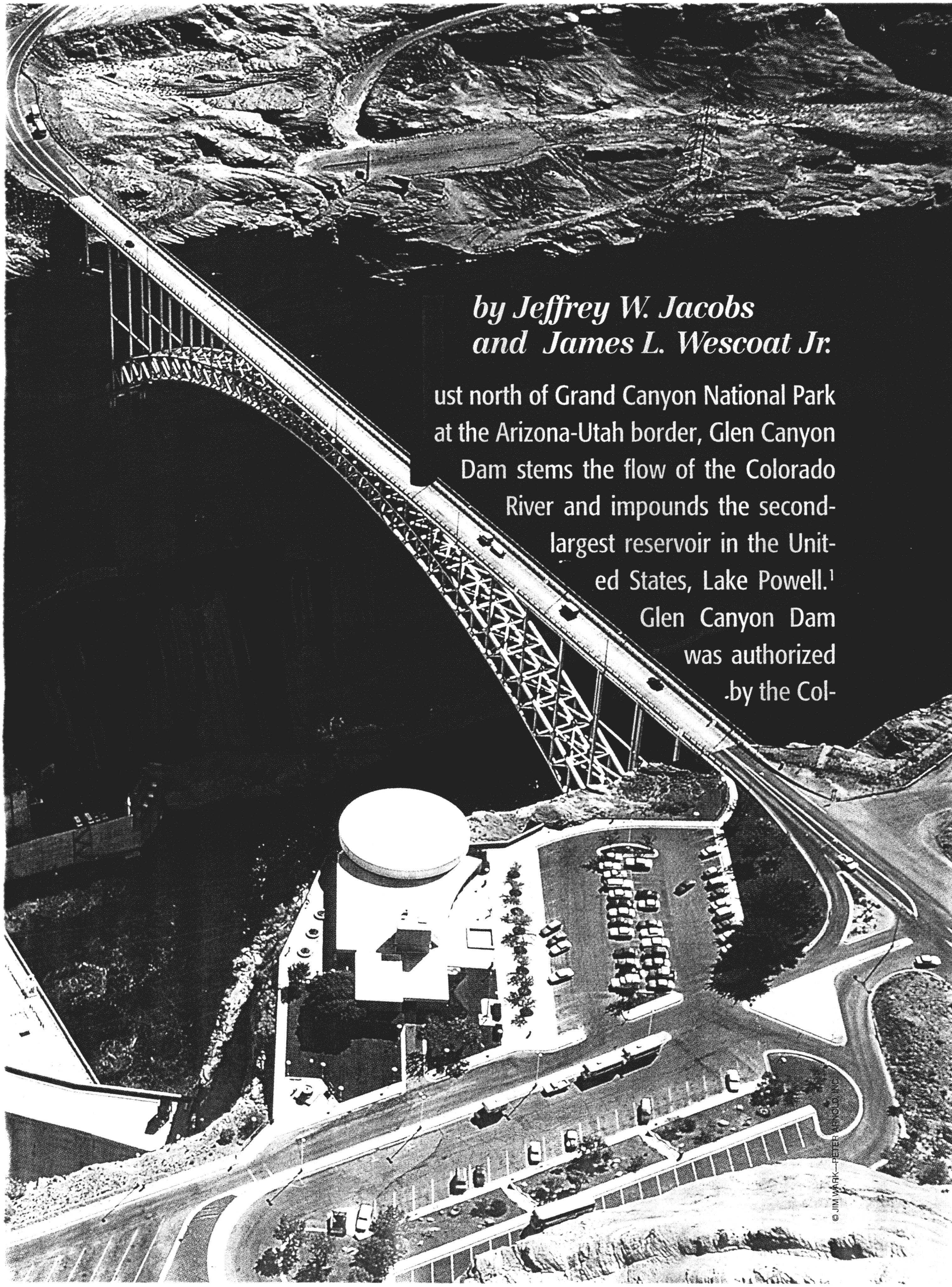
The operations of the Colorado River's Glen Canyon Dam have been the focus of extensive study.



managing resources

Lessons from Glen Canyon Dam

How effectively are social sciences perspectives incorporated into dam operations decisions?



by Jeffrey W. Jacobs
and James L. Wescoat Jr.

ust north of Grand Canyon National Park at the Arizona-Utah border, Glen Canyon Dam stems the flow of the Colorado River and impounds the second-largest reservoir in the United States, Lake Powell.[1] Glen Canyon Dam was authorized by the Colorado River Storage Project Act of 1956 and constructed by the U.S. Bureau of Reclamation.[2] The dam's gates were closed in 1963 and Lake Powell, with an active storage capacity of 24.3 million acre-feet (an acre-foot is the volume of water that covers one acre of land to the depth of one foot), was filled by 1980.

Lake Powell helps meet water delivery obligations to the states of the lower Colorado River basin and Mexico as prescribed by the 1922 Colorado River Compact and other mandates of the "Law of the River."[3] Hydroelectric power generated at Glen Canyon Dam is of vital importance for maintaining peak supply to a multistate power grid operated by the U.S. Department of Energy's Western Area Power Administration.[4]

In addition to water storage and power production, Glen Canyon Dam and Lake Powell also are notable for their impacts on the Colorado River ecosystem. By the time Lake Powell was filled to its capacity in 1980, water had covered grand rock formations, Native American rock drawings, and the cavernous passageways of Glen Canyon. The dam's operations substantially changed resources downstream in the Colorado River ecosystem and in Arizona's Grand Canyon National Park.[5]

The downstream impacts of Glen Canyon Dam have been the focus of one of the most extensive environmental monitoring and research programs in the United States—and the world. In 1982, because of its plans to rewind and upgrade the generators at Glen Canyon Dam, the Bureau of Reclamation initiated the Glen Canyon Environmental Studies (GCES) program to document the effects of dam operations on river-related resources other than hydroelectric power.[6] GCES served to advance scientific understanding of the Colorado River ecosystem and began to include social sciences perspectives in ecosystem studies, but it failed to do so in a fully integrated framework.

The Grand Canyon Monitoring and Research Center (GCMRC) was established in 1995 as part of a larger Adaptive Management Program. Adaptive management strives to redress some of the limitations of conventional natural resource–management approaches and science-policy relationships. It involves a wide range of stakeholders who define management objectives and information needs that guide scientific inquiry and monitoring. The results of this inquiry help support stakeholder recommendations to the secretary of the Department of the Interior. Adaptive management develops testable hypotheses for management alternatives and uses the results of these successive experiments in adjusting traditional river–management principles to meet the evolving economic, technological, physical, and cultural needs of large ecosystems.[7] Each element of adaptive management seeks more scientific and democratic methods of resource management, while recognizing the dynamic tension between those two important aims.

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Native Americans who live on the Havasupai Indian Reservation in Grand Canyon National Park are affected by the operations of Glen Canyon Dam.

Monitoring and studies conducted by GCES and GCMRC have documented and analyzed a wide range of the physical, biological, and cultural impacts of Glen Canyon Dam on the downstream Colorado River ecosystem.[8] This broad research has enhanced knowledge of the effects of dam operations on downstream resources in general and has provided important information for Glen Canyon Dam operations decisions.

Detailed studies have been conducted on river hydrology, sediment transport, and ecological processes; but in contrast, investigations of the social, policy, and economic aspects of Glen Canyon Dam operations have received less attention. Because integration of social and biophysical sciences is a key theme and aim of adaptive management, a lack of emphasis on social sciences research has implications not only for dam operations but also for the effective implementation of adaptive management at Glen Canyon Dam and in other river systems.

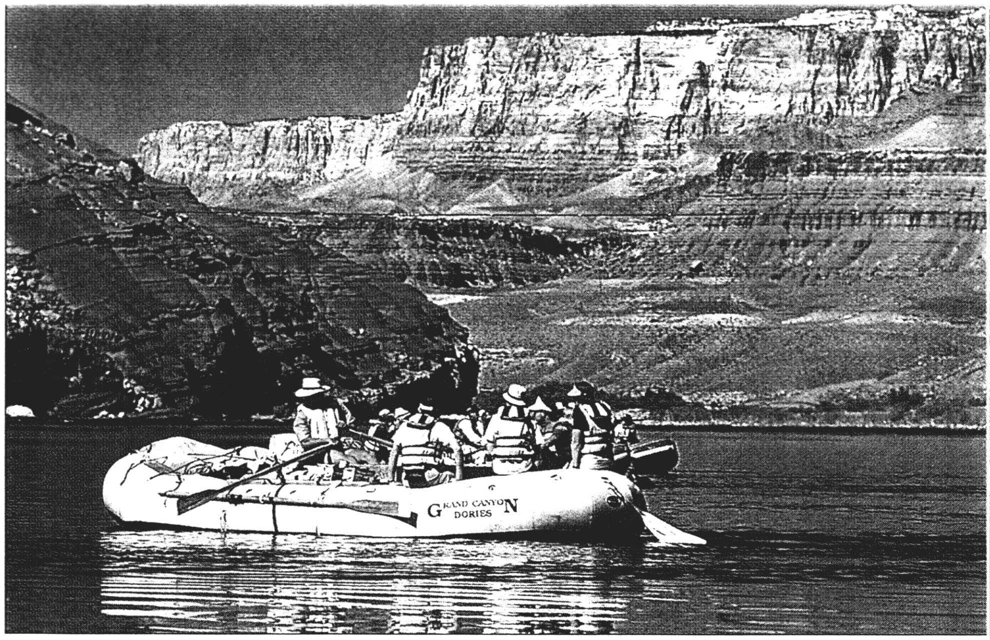
This article tracks the evolution of research initiatives within the GCES and GCMRC programs and the role of that research in promoting operational changes at Glen Canyon Dam. Ways in which social sciences investigations could be broadened to help enhance dam operations are identified, and explanations for the limited amount of social sciences inquiry at Glen Canyon Dam to date are provided. Relevant trends and lessons from U.S. and global water resource management and research, especially the World Commission on Dams report, are also explored.

Before Glen Canyon Dam

In the documented years before Glen Canyon Dam was constructed, flows of the Colorado River in nearby Lee's Ferry, Arizona, were notable for their exceptional variability. A 1946 report by the Department of the Interior was entitled *The Colorado River: A Natural Menace Becomes a National Resource*.[9] Even as recently as the 1986 publication of Marc Reisner's *Cadillac Desert: The American West and Its Disappearing Water*, the author classified the pre-dam Colorado River as "unrivaled for sheer orneriness."[10]

The river's flows could vary between a few thousand cubic feet per second (cfs) to more than one hundred thousand cfs—sometimes over only a few days. The volume of flows at Lee's Ferry between 1920 and 1960 ranged from 4 million to 19 million acre-feet per year.[11] The pre-dam Colorado River carried huge amounts of sediment: Flows past Phantom Ranch in Grand Canyon averaged 85.9 million tons per year during 1941–57.[12] The annual water temperature of the Colorado River also varied substantially, ranging from near 25 degrees Celsius (77°F) in summer months to below 5°C (41°F) in winter. In fact, the Colorado River at Glen Canyon was much warmer in summer before the dam was built, and some analysts have said that the dam made the river more like a headwaters stream than a lower-basin river.[13]

Before Glen Canyon Dam, the Colorado River supported a diverse and unique assemblage of fish species. An 1895 report on Colorado River fish fauna stated, "Over 78 percent of the species of fishes now known from the Colorado Basin are peculiar to it."[14] The unique features of the Colorado's native fish—extremely streamlined bodies, thick and leathery skins, small (if any) scales, and small eyes—reflected the severity of the pre-dam habitat.[15]



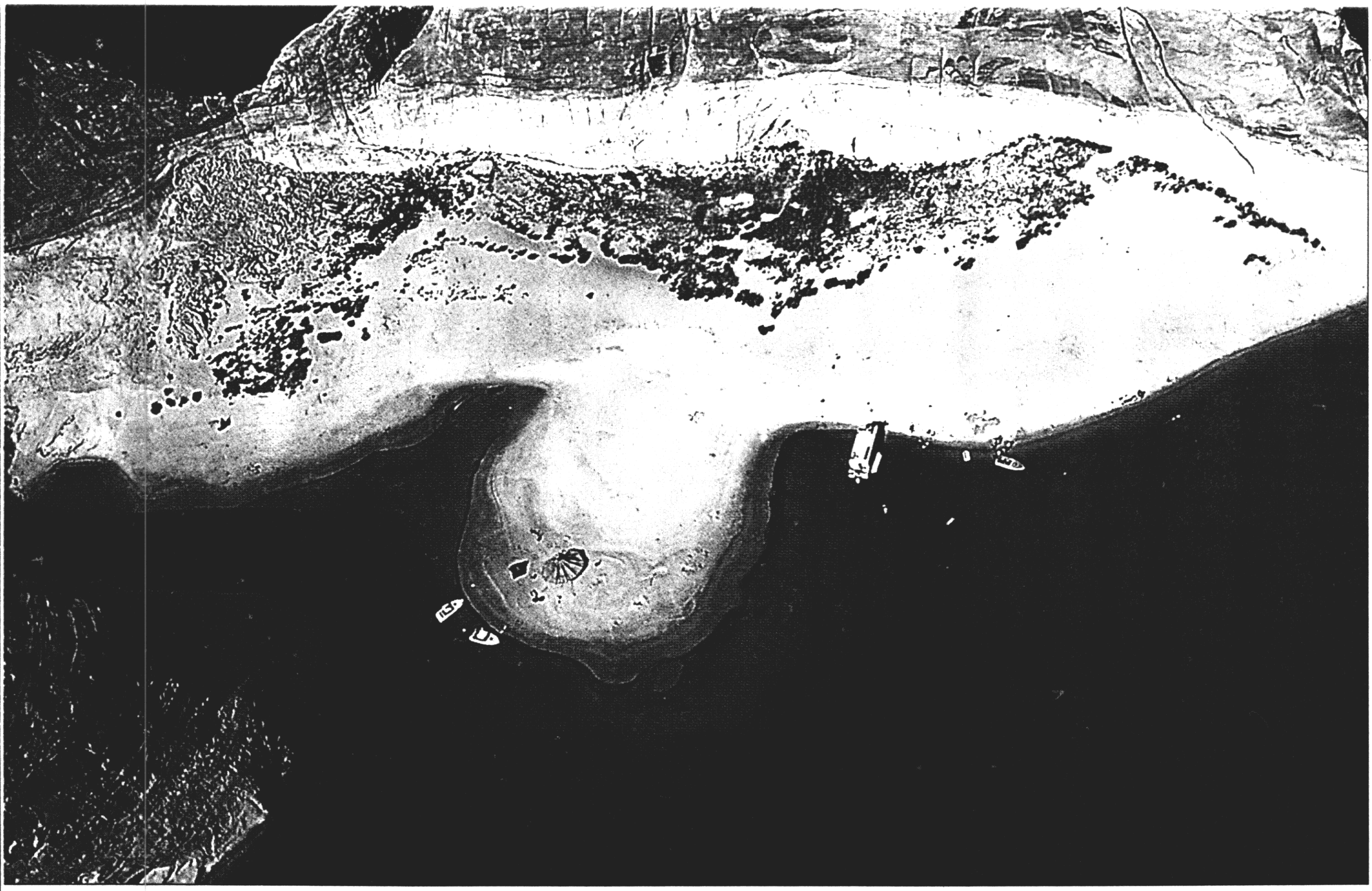
Dam managers can study the experiences of rafters and others who recreate on the Colorado River to better understand how river resources affect perceptions and values.

From antiquity, the canyons of the Colorado River and their fish and wildlife have held important spiritual values. The creation stories for several Native American tribes originate in Grand Canyon.[16] Some Native Americans only enter the canyon for ritual purposes after intense preparations that follow sacred paths and secret practices. Burial sites in Grand Canyon also hold sacred value, but they have been threatened by reservoir-induced erosion and recreational activity resulting from dam operations. For example, operations schedules that call for large fluctuations in the level of Lake Powell can increase the rates of erosion at burial sites. A major research program now monitors such erosion and tests alternative measures for mitigation. Some tribes (such as the Hopi) eschew river recreation, while others depend economically upon recreational activities and resources provided by the dam.

At the same time, Grand Canyon, Lake Powell, and even Glen Canyon Dam itself have enormous cultural appeal.[17] From the Hopi story of Tiyo floating down the river on a log, to John Wesley Powell's 1895 *Exploration of the Colorado River and its Canyons*, in which Powell was strapped to a chair on the deck of his boat, this reach of the Colorado River has long inspired contemplation and adventure.[18] And from early river runners to the modern recreational boating industry, the Colorado River has also supported hunting, ethnobotanical gathering, and fishing economies. Many of the river corridor's early cultural values have been reshaped in complex ways by both the dam, which flooded beautiful sacred and secular sites upstream, and its operations, which altered floodplain use, settlement, and recreational experiences downstream. Releases from the dam generally peak in concert with electric power demand, diminishing the recreational, fishing, and aesthetic value of the area.

Construction and Initial Operations

Construction of Glen Canyon Dam began shortly after it was authorized by the 1956 Colorado River Storage Project Act. The dam was constructed largely to help the upper basin meet contractual water delivery obligations set forth by the 1922 Colorado River Compact, which divided the Colorado River basin into an upper basin (Colorado, New Mexico, Wyoming, and Utah) and a lower basin (Arizona, California, and Nevada).[19] Lee's Ferry, Arizona, divides the basin into its upper and lower portions. The Colorado River Compact



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One of the largest reservoirs in the United States, Lake Powell has been notable for its impacts on the Colorado River ecosystem since it was filled in 1980.

allocates 7.5 million acre-feet of water per year to the upper basin and requires the delivery of at least 75 million acre-feet of water over any consecutive 10-year period to the lower basin. Glen Canyon Dam allows the upper basin to reliably meet this water delivery obligation. It also is the consummate "cash register dam," as revenue generated from its hydropower sales has been used to finance a dozen or so other water projects in the upper Colorado River basin as part of the Colorado River Storage Project Act.[20]

Except for periods of flood and drought, operations at Glen Canyon Dam varied little after its gates were closed in 1963. In 1983, however, exceptionally heavy snowfall associated with El Niño conditions in the upper Colorado basin led to significant runoff into the reservoir. Lake Powell rose rapidly, requiring maximum releases through the dam's turbines, spillways, and jet tubes that resulted in some surprising effects. Beaches in Marble Canyon (downstream from Glen Canyon Dam) were replenished by resuspension and deposition of sediments from the riverbed rather than eroded (erosion was expected to occur under such high flow conditions).[21]

Exclusive of that event, daily water releases until 1991 followed a common pattern that reflected variations in peak demand for hydropower: increasing through the morning, reaching near-maximum flows of 31,500 cfs during the day, and steadily decreasing through the evening, with flows ramping back up after early-morning minima (which ranged from roughly 1,000 cfs in winter to 3,000 cfs in summer).[22] The goal of this daily pattern of fluctuations was to maximize revenue from hydropower sales, even though hydropower was listed in the authorizing legislation as "an incident to the foregoing purposes" of the dam.[23] The Bureau of Reclamation and the Western Area Power Administration sought to maintain this reservoir release schedule, but even if there had been a desire to change operations, there was little scientific basis upon which they could have been adjusted. Before the initiation of the Glen Canyon Environmental Studies program, the needs of—and the effects of the release schedule on—endangered species, tribal groups, and recreational users had not been studied sufficiently.

In the early 1980s, the Bureau of Reclamation was considering rewinding Glen Canyon Dam's generators, increasing generator capacity, and adjusting operations to increase the output of peaking power and maximize revenue from hydropower sales. Pursuant to the 1969 National Environmental Policy Act, these changes would have required a full environmental impact statement (EIS) of the projected effects of the new operations plans. The bureau hoped to avoid conducting a full EIS, but to support this decision it needed data on the environmental impacts of Glen Canyon Dam operations. To provide these data, the Bureau of Reclamation established GCES in 1982.

Changes in Dam Operations

The Glen Canyon Environmental Studies were conducted in two phases: Phase I from 1982 to 1988 and Phase II from 1988 to 1996. GCES Phase I focused on two questions:

- Are current operations of the dam, through control of the flows in the Colorado River, adversely affecting the existing river-related environmental and recreational resources of Glen and Grand Canyons? and
- Are there ways to operate the dam, consistent with the mandate of the Law of the River, that would protect or enhance the environmental and recreational resources?

Initial scientific research within the GCES program was narrowly framed. Environmental data were to be collected primarily near the dam, and analyses of operating regimes that might result in substantial reductions in hydropower revenue were omitted. Investigations of the cultural and aesthetic values of the region were also initially off-limits.[24] But as a committee of the National Research Council (NRC) that reviewed GCES noted, "Rather than coming to a quick conclusion, however, the GCES merely proved with increased certainty the need for environmental studies of broader scope."[25] Studies from Phase I concluded that Glen Canyon Dam operations were affecting downstream environmental and recreational resources in negative and positive ways and that operations could be adjusted both to minimize losses and to protect these resources.[26] At the conclusion of these studies in 1988, the Bureau of Reclamation determined that additional research was necessary to more fully address the key research questions within GCES. To gather additional data on specific operational elements, Phase II was begun.

When it was launched, Phase II was to last only four or five years. But this timetable was changed on 27 July 1989, when Secretary of the Interior Manuel Lujan Jr. announced that in light of scientific evidence gathered during Phase I and in response to increasing concern over the downstream impacts of dam operations, a full environmental impact statement was to be prepared. The research schedule of Phase II was subsequently accelerated by the use of "research flows" to provide data for the EIS. Conducted between June 1990 and July 1991, each of these two-week research flows consisted of 3 days of steady 5,000-cfs flows and 11 days of either steady or fluctuating flows.[27] The research helped improve understanding of short-term ecological responses to hydrologic changes.

In 1991 the research flows were discontinued and the daily operating rules of Glen Canyon Dam were revised. A set of interim flow regulations was established for use until completion of the EIS.[28] These interim flows were intended to reduce the environmental impacts of dam operations, and they represented a bridge between historical operating practices and future practices that would be based upon the EIS results. The operating rules signaled the willingness of the Bureau of Reclamation and Western Area Power Administration to accept a reduction in hydropower revenues to protect and enhance downstream resources. The operating rules were set within a broader institutional context by the Grand Canyon Protection Act of 1992, which required Secretary Lujan to operate Glen Canyon Dam "in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established."[29]

The interim flows remained in effect until October 1996, when the new secretary of the interior, Bruce Babbitt, signed a Record of Decision establishing new water release schedules and flow guidelines. (Table 1 below offers details of the Record of Decision.) The EIS, which was completed in 1995, compared the downstream impacts of nine alternative dam operations. The new flow rules were based upon a "modified low-fluctuating flow" scenario described as one of these nine opera-

Table 1. Operating limits of the 8 October 1996 Record of Decision

Daily releases	Cubic feet per second	Operating limits
Minimum release	8,000 5,000	7 a.m.–7 p.m. 7 p.m.–7 a.m.
Maximum release	25,000	Exceeded during beach/habitat-building flows
Allowable daily fluctuations	5,000	For monthly release volumes less than 600,000 acre-feet
	6,000	For monthly release volumes of 600,000–800,000 acre-feet
	8,000	For monthly release volumes greater than 800,000 acre-feet
Ramp rates	4,000 cfs/hour up 1,500 cfs/hour down	

NOTE: Operating limits are subject to emergency exception criteria for emergency releases and continuing discussion of hydropower regulation fluctuation. Ramp rates are the limits at which discharge through the dam can be increased ("up") and decreased ("down").

SOURCE: National Research Council, 1996.

tions alternatives.[30] The 1996 Record of Decision guides the operations of Glen Canyon Dam today.

The Evolving Role of Science

The Grand Canyon Monitoring and Research Center (GCMRC) was established in 1995 to help meet ecosystem monitoring requirements mandated by the 1992 Grand Canyon Protection Act. While GCMRC continues some traditional GCES science programs, it represents a unique effort in ecosystem monitoring for dam operations policies. Although GCES was originally established as a short-term effort to monitor impacts of dam operations directly below the dam and to provide data for an EIS, GCES eventually expanded its spatial and disciplinary coverage into an ambitious environmental studies program. Its expansion, however, tended to be ad hoc and poorly integrated across disciplines, landscapes, and policy arenas.

In contrast, GCMRC was from its inception part of a more formal ecosystem monitoring and adaptive management framework defined in the 1995 Glen Canyon Dam EIS and the 1996 Record of Decision. The center operates within the Adaptive Management Program, which includes the secretary of the interior's designee, Adaptive Management and Technical Work Groups, and independent science review groups.

The Adaptive Management Work Group is a federal advisory committee composed of representatives from 25 different organizations that include cooperating agencies and tribal groups, the basin states, environmental groups, recreation interests, and federal power purchase contractors. It facilitates the program and makes recommendations to the secretary of the interior to meet the requirements of the Grand Canyon Protection Act.

The Technical Work Group's membership is similar to that of the Adaptive Management Work Group, but it also includes a representative from the U.S. Geological Survey. Its role is "to articulate to the GCMRC the science and information needs expressed in the objectives defined by the AMWG, and to assist in recommending science priorities."[31] In practice, the Technical Work Group conducts month-to-month discussions regarding the science, policy, and politics of adaptive management.[32]

The roles and processes of scientific evaluation and advising have also changed with the introduction of adaptive management into Glen Canyon Dam operations. As noted above, the use of the Adaptive Management Program grew out of concerns that the more traditional resource-management organizations and policies did not adequately reflect the science of ecosystem dynamics and were thus unable to appropriately adjust to rapid and unforeseen environmental changes. In an adaptive management approach, resource–management policies are designed as scientific experiments. The environmental outcomes of these policies are closely monitored, and the results are used to inform subsequent policy adjustments. Adaptive management encourages an ecosystem-level approach to resource management and encourages close collaboration among scientists, managers, and other stakeholders on key policy decisions.

Within the Adaptive Management Program, there is to be a "close functional relationship between resource stakeholders and managers and the Center's science group."[33] The Adaptive Management Program is in the process of establishing an independent science advisory board.[34] In addition, each GCMRC program has convened scientific protocol evaluation program panels to identify and prioritize science issues.[35] GCMRC oversees scientific monitoring and research in response to prioritized management objectives and research needs established by the Adaptive Management Work Group. The center also issues open calls for proposals to conduct various scientific studies in the Colorado River ecosystem below Glen Canyon Dam. GCMRC promotes science and adaptive management through programs in biological, cultural, and physical resources.

The biological resources program addresses management objectives within two programmatic activities: aquatic and terrestrial monitoring. Specific studies address water quality, the aquatic food base, native and non-native fish species, riparian vegetation (situated along or near a riverbank), avifauna (regional birds), and endangered species. The cultural resources program has three primary components: core monitoring and research activities, cooperative tribal projects, and individual tribal projects. The physical resources program focuses on the sources, sinks, and rates of movement of sand and deposition in Grand Canyon. Research and monitoring focus on how to maintain adequate volumes and appropriate structures of sand deposits to preserve and enhance associated hydrologic, cultural, ecological, and recreational resources.

Integration across these science programs was initially limited, but there has been progress in linking the physical and cultural resources programs (through studies of the erosion of sacred sites), biological and cultural resources programs (through ethnobotanical studies), and physical and biological programs (through conceptual modeling).[36] Integration through the colocation of research projects and reach-based investigations is also progressing. Curiously, the one major line of research from the Glen Canyon Environmental Studies that has received less support in GCMRC—and that has potential roles in both scientific integration and adaptive management—is socioeconomic monitoring and research.

Social Sciences and Glen Canyon Dam

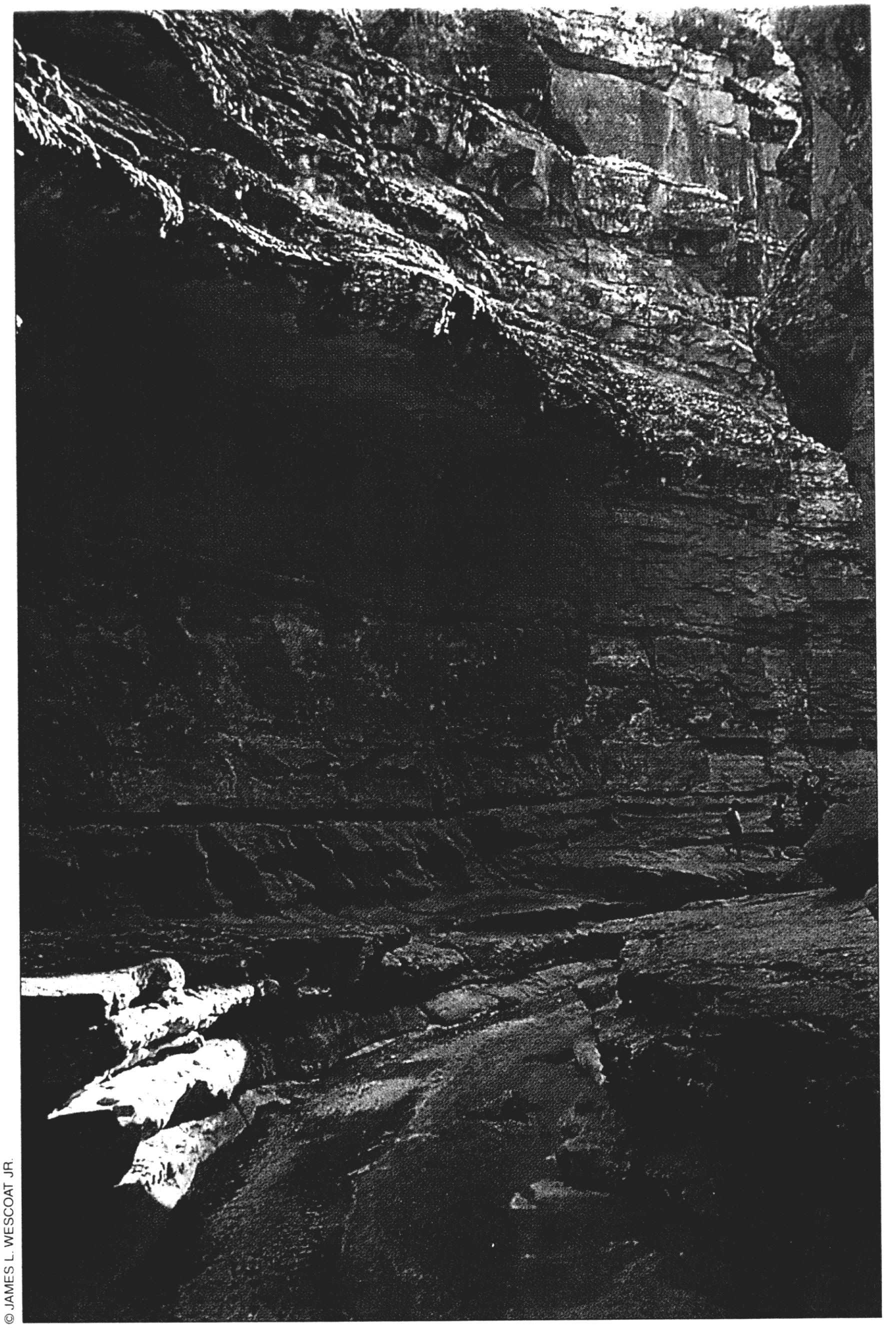
Although GCES and GCMRC science studies have emphasized biological and physical sciences, a number of valuable social sciences investigations have been conducted. The initial social sciences research within the GCES program focused on recreational users in Grand Canyon. GCES Phase II added Native American cultural studies that included archaeological sites of significance to tribal groups. Social sciences inquiry within the Adaptive Management Program and GCMRC has been addressed largely by the center's cultural resources program. In addition to the program's three primary components, there is a programmatic agreement between the U.S. Bureau of Reclamation, the U.S. National Park Service, the Advisory Council on Historic Preservation, and seven tribal groups to monitor and mitigate the impacts of dam operations on tribal historic properties.

Social sciences research has received less emphasis than physical and biological sciences research within the GCES and GCMRC programs. In the 1998 GCMRC budget, for example, the biological resources program received five times the amount of funding as the cultural resources program, while the physical resources program was allocated more than twice the amount allocated to cultural resources. These disparate levels of funding prompt larger questions: What light does social sciences inquiry shed on the effects of dam operations? Should GCMRC be conducting more or less social sciences research? Should social sciences research be funded at similar levels as physical and biological research?

Indeed, dams alter a river system's physical and biological processes, but they have many social and cultural implications as well. Dams are constructed to achieve social goals and human needs. As the World Commission on Dams stated, "the 'end' that any project achieves must be the sustainable improvement of human welfare."[37] The means to attaining this end requires expertise in engineering and physical sciences to properly locate and size a dam and to ensure acceptable safety levels. But full attainment of a dam's social and human goals requires knowledge of its economic and institutional implications, as well as the human perceptions and cultural values that shape those implications.

The operations of U.S. federal dams like Glen Canyon Dam ultimately distribute public benefits and costs. Flows from Lake Powell and Glen Canyon Dam can be adjusted to optimize the benefits for hydropower contractors and river rafters as well as for Native American tribes and the environment. While these flows are guided and limited by engineering and hydrological considerations, determining the proper balance between multiple beneficiaries requires consideration of the social dimensions—economic, institutional, and cultural—of water resources.

Glen Canyon Dam was constructed to provide hydroelectric power and deliver water to residents in the Colorado River basin and surrounding areas. For years, daily dam operations were guided almost exclusively by the goal of maximizing revenue from hydropower sales while meeting the upper basin's water delivery obligations. In 1956, relatively little federal concern was given to values such as whitewater rafting and protection of individual species. But by 1980, whitewater rafting had become a highly profitable industry in Grand Canyon, and Congress had passed the National Environmental Policy Act (1969) and



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The Cathedral Wash tributary canyon affords hikers an easily accessible path from Lee's Ferry to the Colorado River.

the Endangered Species Act (1973). Environmental values had shifted, aesthetic considerations had changed, and Native American tribes played a greater role in setting environmental policies. These economic, scientific, cultural, and technological changes eventually resulted in calls for adjustments to the longstanding operating regime. The World Commission on Dams explained this phenomenon as follows:

> *Dams and the context in which they operate are not seen as static over time. Benefits and impacts may be transformed by changes in water use priorities, physical and land use changes in the river basin, technological developments, and changes in public policy expressed in environment, safety, economic and technical regulations. Management and operation practices must adapt continuously to changing circumstances over the project's full life and must address outstanding social issues.*[38]

Social and economic changes are inevitable. Social sciences inquiry is therefore crucial in ensuring that dam operations are appropriately adjusted to these changes. Additional inquiries in the social sciences could complement GCMRC's cultural resources program and help integrate its research programs. Several types of social sciences investigations could enhance Glen Canyon Dam operations—and those of other dams worldwide—including environmental perception, resource valuation, organizational and policy research, ex post evaluation, and interbasin river comparisons.

Environmental Perception

According to the Grand Canyon Protection Act of 1992, one of the functions of Glen Canyon Dam is to protect and enhance the values of Grand Canyon National Park and Glen Canyon National Recreation Area. Because these values include cultural resources, comprehensive operations decisions require information on cultural values and how they are affected by dam operations. To that end, the Adaptive Management Work Group includes representatives from six Native American tribes who live in and near Grand Canyon.

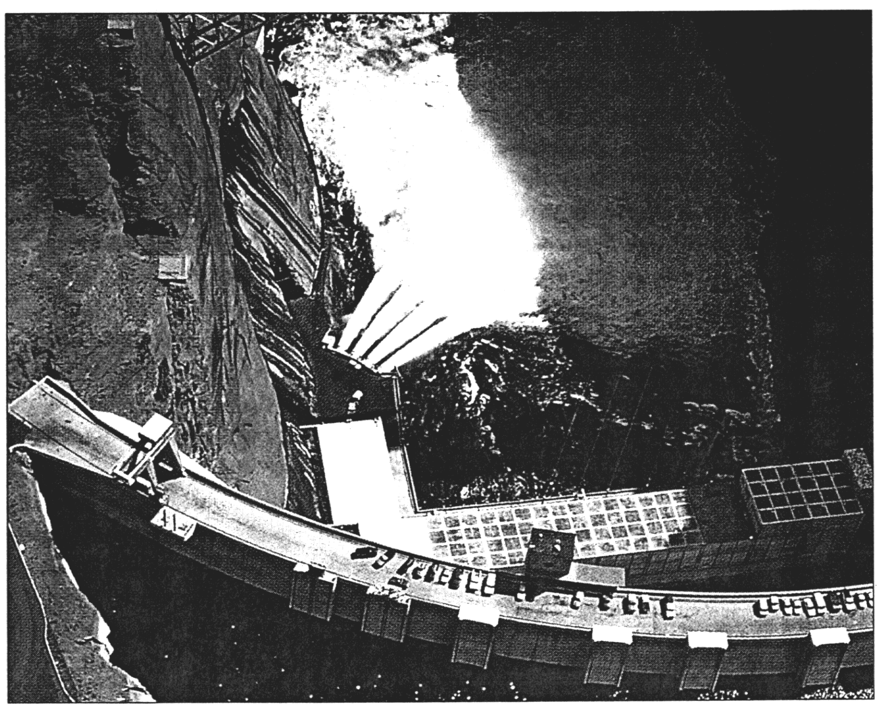
Research on the environmental perceptions of users—such as tribal residents, hikers, rafters, and anglers—of the Colorado River ecosystem and Grand Canyon can enhance understanding of what people experience in these areas and how the river's resources affect perceptions and experiences. If these studies are conducted across different flow regimes—and among different cultural groups—in the Colorado River ecosystem, dam managers can better understand how operations affect perceptions and values and how they should be adjusted.

The U.S. National Park Service has conducted extensive research on recreational perceptions and experiences in Grand Canyon National Park. GCMRC also has taken an important step in this direction by funding a research project on a river "recreational opportunity spectrum" downstream of Glen Canyon Dam, conducted by the Department of Leisure Studies at the University of Illinois at Urbana-Champaign. In addition, the 2001 GCMRC Science Symposium included studies of the relationships between river flow levels and recreational experiences.[39] These types of investigation deserve additional attention and support.

Resource Valuation

Dams and their operations provide values to a range of users beyond the immediate benefits of hydroelectric power, yet dam operations agencies in the United States have been criticized for improperly favoring some users over others. One explanation of such criticisms is that some of the values associated with dam and reservoir operations have not been clarified and explained. Moreover, many of these values are not bought and sold in markets and are not as readily monetized as market-based values such as hydroelectricity. Nonmarket values include values that hikers place on recreational experiences and values that Native Americans place on Grand Canyon's spiritual qualities.

Valuation studies first entail identifying the values in question, then striving to quantify (and monetize, if possible) those values affected by dam operations. Economists have developed a variety of methods to help identify and quantify



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Social sciences inquiry is key in adapting the management and operations of Glen Canyon Dam to meet the needs of all of its beneficiaries.

nonmarket values.[40] For instance, contingent valuation methods measure values through carefully worded surveys that determine consumers' willingness to pay for nonmarket goods, such as the preservation of a specific species or the enjoyment of a beautiful landscape. Although there is a continuing debate over the precision of contingent valuation studies in policy decisions, the application of this and other methods for gauging nonmarket values has become more frequent.

More thorough valuation of the benefits related to dam operations could enhance dam managers' understanding of the link between release schedules and the public distribution of benefits and costs. In determining the time of year when controlled high flows would yield the highest value of ecosystem-based goods, for example, or how different flows would affect the economics of sport fishing, valuation studies could increase the transparency of the benefits that are gained or lost among users and thus aid in dam operations decisions.[41]

Organizational and Policy Research

A tenet of adaptive management is that monitoring and research should be used to improve stakeholders' understanding of environmental conditions and changes, thereby contributing to more effective decisionmaking. But organizations learn in different ways and at different rates. Organizations may be limited in their flexibility and capacity to adapt to new scientific information; these limitations may differ within and among organizations.[42]

Although it is often assumed that more scientific research inevitably leads to better policy decisions, research has demonstrated that substantial modeling and science expenditures may have only limited effects on subsequent policy decisions.[43] For example, if organizations within adaptive management programs are not "learning" from the findings of monitoring programs, or if policies are not being adjusted in response to new information, progress toward adaptive management will be impeded. If the obstacles to policy changes and organizational learning are not identified—and remedied—links between policy and science may be short-circuited, slowing progress toward both adaptive management and ecosystem protection. Evaluation of policy and organizational processes can help decision makers better understand why dam operations policies may not be adapting to shifting scientific and social realities. Although formal institutional research focusing on the Glen Canyon Dam Adaptive Management Program has been limited to date, the development of an Adaptive Management Practitioners' Network represents an innovative and promising approach to these issues.[44]

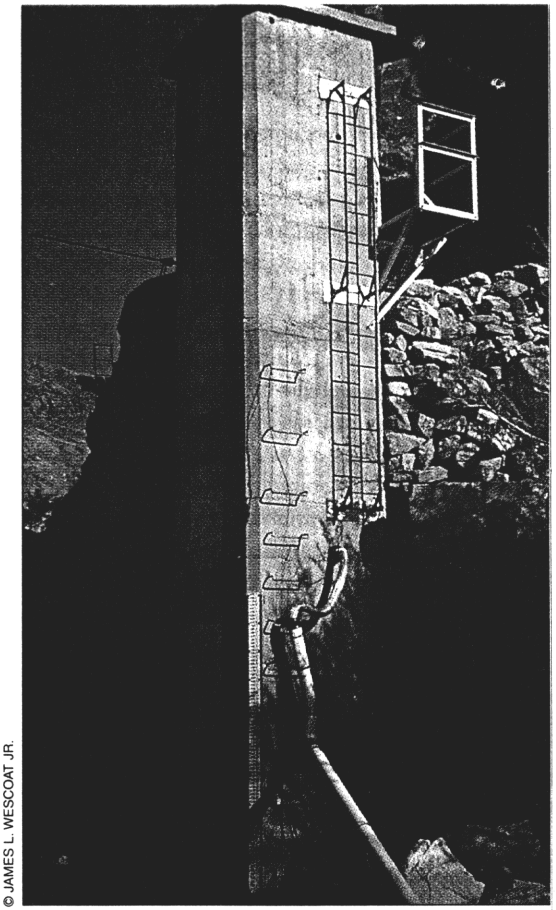
Ex Post Evaluation

In 2000, the World Commission on Dams noted that "the paucity of monitoring and evaluation activity once a large dam is built has reduced the basis for learning from experience."[45] Retrospective, or ex post, evaluation of outcomes from dam operations can help indicate whether the flows of benefits from the dam and reservoir are being wisely allocated.

The extensive history of ex post evaluation at Glen Canyon Dam, and within the GCES and GCMRC programs, represents one of the most comprehensive monitoring and evaluation efforts of a single dam in the United States—and perhaps the world.[46] Theories and methods from the social sciences—economics, history, law, geography, anthropology, and policy sciences—can contribute to more comprehensive ex post studies at Glen Canyon Dam and elsewhere.

River Basin Comparisons

Comparisons of experiences with dam operations in different reaches of the Colorado River basin, and in different regions of the world, may yield important insights.[47] Are operations of other dams being adjusted to enhance river ecology? What adjustments elsewhere have been successful? What are the primary barriers elsewhere to adjusting dam operations? What types of organizations are able to quickly adjust dam operations to changing conditions? The answers to these types of key science-policy questions can help dam managers draw upon the successes and setbacks of other dam-operating agencies and policies, and they can help identify strategies for conflict resolution and improvement of social and environmental outcomes. Water managers and scientists in different river systems where adaptive management is being pursued could evaluate the experiences of the Adaptive Management Program at Glen Canyon Dam, while stakeholders and GCMRC scientists could review similar efforts of other water managers and organizations.



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This gauging station measures the flows from the upper basin to the lower basin of the Colorado River, as prescribed by the 1922 Colorado River Compact.

Challenges to Integrating Social Sciences Research

Given the potential values of social sciences inquiry, it might seem natural to question why it has not been a focus of the science programs at Glen Canyon Dam. Several barriers may exist to incorporating social sciences inquiry, some of which have been identified and discussed elsewhere.[48]

The resources available for scientific research programs, including the Adaptive Management Program, are limited. Biological and physical sciences issues are essential to understanding changes in a river's ecosystem. There is a need for long-term monitoring of biological and physical variables, and these studies may acquire historical momentum that encourages their continued priority. Furthermore, increased funding for one program or study may lead to decreased funding for another.

Also, social sciences aspects of U.S. federal water resource–management and research programs have historically received less emphasis than traditional engineering, physical, and biological sciences approaches. Agencies such as the Bureau of Reclamation and the Geological Survey have comparatively few social scientists on their staffs, which may limit the inclusion of such perspectives. Water resource managers may be less familiar and less comfortable with social sciences research approaches than they are with engineering and physical sciences methods.

Water resource managers are often skeptical about working with social sciences "experts." Managers may feel—and often rightly—that they are well informed on topics like organizational behavior. Experienced federal water resource employees may be willing to defer to biological scientists' expertise on fisheries, but they may feel that they know as much about agencies' decision-making processes as external analysts.

Social sciences research often investigates politically charged or sensitive issues (as does all scientific research—albeit less explicitly). Stakeholders who are associated with natural resource–management agencies and programs want to study aspects of the natural resource system to address common questions. Whatever their interest in the management of natural resources, they tend to resist being a subject of inquiry themselves. However, the successes and failures of the adaptive management process—both internally in terms of organizational processes and externally in terms of representing and fulfilling social aims—can be most fully understood through scientific inquiry of the same sort directed toward sediments, algae, and archaeological sites. A key challenge for adaptive management programs such as that at Glen Canyon Dam is to ask what types of political inquiry or policy sciences—if any—can have utility, credibility, and legitimacy.

Conclusions and Prospects

The GCES and GCMRC science programs in the Colorado River ecosystem represent science-policy research of regional, national, and international significance. The environmental impacts of Glen Canyon Dam operations have been analyzed extensively, and the Adaptive Management Program for the dam and the Colorado River ecosystem provides lessons for other agencies and other nations interested in applying the emerging concept of adaptive management to river ecosystems.

Historical changes in Glen Canyon Dam operations reflect evolving social goals and preferences, as well as scientific findings and their applications to policy decisions. The dam and the GCES and GCMRC programs illustrate the interwoven challenges involved in adjusting dam operations to meet social and economic changes. Even with extensive ecosystem monitoring efforts, findings from physical and biological sciences are only partially adequate for understanding how well a dam is meeting its social and human goals, and how the dam's operations might be properly adjusted to reflect social and economic changes.

Social sciences inquiry within the GCES and GCMRC programs has expanded in creative and useful ways. Additional studies on environmental perception, resource valuation, policy and organizational issues, and interbasin comparisons would augment the center's socioeconomic programs. These studies are critical to enhancing understanding of the relationships among Grand Canyon's users, organizations, policies, and ecosystem, so it is important to address barriers inhibiting these studies and use of their results.

The Adaptive Management Program and GCMRC have made impressive advances in incorporating science and stakeholder views into dam operations decisions. Scientific findings from GCES and GCMRC have improved knowledge of how dam operations affect the canyon's resources. But further progress may be hindered without social sciences evaluation of specific questions such as: How do users perceive and value the canyon's resources? What are the values of resources being considered in tradeoff decisions among beneficiaries? How well are the program's organizations and policies adjusting to new scientific information? How effective is adaptive management overall? Overcoming barriers to additional social sciences inquiry—and incorporating social sciences results into key dam operations decisions—may represent an important step toward a successful future for the Adaptive Management Program, Glen Canyon Dam, the residents of the Colorado River basin, and Grand Canyon visitors from around the world.

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NOTES

1. For a historical study, see R. Martin, *A Story that Stands Like a Dam: Glen Canyon and the Struggle for the Soul of the West* (New York: Henry Holt, 1990).

2. *Colorado River Storage Project Act of 1956*, U.S.

Code, vol. 43, sec. 617 (1956).

3. For a concise treatment of the Law of the River, see N. Hundley, "The West Against Itself: The Colorado River—An Institutional History," in G. Weatherford and F. L. Brown, eds., *New Courses for the Colorado River: Major Issues for the Next Century* (Albuquerque: University of New Mexico Press, 1986), 9–49. For a detailed compilation of original documents, see U.S. Department of the Interior, *Reclamation and Related Laws Annotated*, 4 vols. (Washington, D.C., 1972–89).

4. Glen Canyon Dam's changing roles in western hydropower are documented in Western Area Power Administration, *Replacement Resources Methods Report* (2001), accessed via http://www.wapa.gov/crsp/l6300doc.dir/replreso.htm on 24 October 2001. Glen Canyon Dam also provided emergency power during the California energy crisis from February 2001 to May 2001. A discussion is available at http://www.wapa.gov/crsp/sigevent.htm, accessed on 24 October 2001.

5. A poignant photographic obituary of Glen Canyon was provided for the Sierra Club in E. Porter, *The Place No One Knew: Glen Canyon on the Colorado* (San Francisco: Sierra Club Books, 1963).

6. The National Research Council's (NRC) Water Science and Technology Board has published the following assessments of the Glen Canyon Environmental Studies (GCES): *River and Dam Management: A Review of the Bureau of Reclamation's Glen Canyon Environmental Studies* (Washington, D.C.: National Academy Press, 1987); *Colorado River Ecology and Dam Management: Proceedings of a Symposium May 24–25, 1990 Santa Fe, New Mexico* (Washington, D.C.: National Academy Press, 1991); and *River Resource Management in the Grand Canyon* (Washington, D.C.: National Academy Press, 1996). An NRC committee reviewed the Grand Canyon Monitoring and Research Center's (GCMRC) strategic plan in *Downstream: Adaptive Management of Glen Canyon Dam and the Colorado River Ecosystem* (Washington, D.C.: National Academy Press, 1999). In addition, GCES assumed substantial responsibility (some believe to its distraction) for preparing an environmental impact assessment of dam operations alternatives. See U.S. Bureau of Reclamation, *Operation of Glen Canyon Dam: Final Environmental Impact Statement* (Washington, D.C., 1995).

7. For more information on adaptive management, see C. Walters, *Adaptive Management of Natural Resources* (New York: McGraw Hill, 1986); L. H. Gunderson, C. S. Holling, and S. S. Light, eds., *Barriers and Bridges to the Renewal of Ecosystems and Institutions* (New York: Columbia University Press, 1995); *Conservation Ecology*, accessed via http://www.consecol.org on 24 October 2001; K. Lee, *Compass and Gyroscope* (Covelo, Calif.: Island Press, 1993); and most recently, The Social Learning Group, *Learning to Manage Global Environmental Risks*, 2 vols. (Cambridge, Mass.: MIT Press, 2001).

8. Hundreds of studies have been commissioned and completed. Because many remain unpublished reports, the best sources of information are web pages that post reports and bibliographies for GCMRC, accessible via http://www.gcmrc.gov, and the Adaptive Management Program, accessible via http://www.uc.usbr.gov/amp. Detailed syntheses of geomorphological, biological, fisheries, and cultural heritage studies have been prepared for GCMRC. See, for example, J. C. Schmidt and J. B. Graf, *Aggradation and Degradation of Alluvial Sand Deposits, 1965 to 1986, Colorado River, Grand Canyon National Park, Arizona*, U.S. Geological Survey Professional Paper 1493 (Washington D.C., 1990); R. Valdez and S. Carothers, *The Aquatic Ecosystem of the Colorado River in Grand Canyon*, Grand Canyon Data Integration Project Synthesis Report prepared for the U.S. Bureau of Reclamation, 1998; D. Patten, *Integration and Evaluation of Glen Canyon Environmental Studies Research Findings: The Grand Canyon Riverine Ecosystem—Functions, Processes and Relationships Among Biotic and Abiotic Driving and Response Variables* (Salt Lake City, Utah: U.S. Bureau of Reclamation; Flagstaff, Ariz.: GCMRC, 1998); and T. J. Ferguson, *Ongtupqa Niqw Pisisvayu* (Salt Canyon and the Colorado River), *The Hopi People and Grand Canyon*, produced by the Hopi Cultural Preservation Office, under the guidance of the Hopi Cultural Resources Advisory Task Team and under contract with the U.S. Bureau of Reclamation (Tucson: Anthropological Research, 1998).

9. U.S. Department of the Interior, *The Colorado River: A National Menace Becomes a Natural Resource* (Washington, D.C., 1946).

10. M. Reisner, *Cadillac Desert: The American West and Its Disappearing Water* (New York: Penguin Books, 1986), 121.

11. See U.S. Bureau of Reclamation, note 6 above, page 78.

12. Ibid., page 90.

13. See J. V. Ward and J. A. Stanford, "The Serial Discontinuity Concept of Lotic Ecosystems," in T. Fontaine and S. Bartell, eds., *Dynamics of Lotic Ecosystems* (Ann Arbor, Mich.: Ann Arbor Science Publishers, 1983).

14. B. Everman and C. Rutter, "The Fishes of the Colorado Basin," *Bulletin of the U.S. Fish Commissioner* 14 (1895): 473–86.

15. W. L. Minckley, "Native Fishes of the Grand Canyon: An Obituary?" in *Colorado River Ecology and Dam Management: Proceedings of a Symposium May 24–25, 1990 Santa Fe, New Mexico* (Washington, D.C.: National Academy Press, 1991), 124–77.

16. See Ferguson, note 8 above.

17. See D. Harpman, M. Welsh, and R. Bishop, "Nonuse Economic Value: Emerging Policy Analysis Tool," *Rivers* 4, no. 4 (March 1995): 280–91.

18. J. W. Powell, *The Exploration of the Colorado River and its Canyons* (1895; reprint, New York: Dover Publications, 1961).

19. *Colorado River Compact of 1922*.

20. See note 2 above; and see Hundley, note 3 above.

21. See Schmidt and Graf, note 8 above. These authors also found that many beaches in the canyon were subsequently eroded during high flows of 1984–86.

22. NRC, *River Resource Management in the Grand Canyon*, note 6 above, page 51.

23. See note 2 above, sec. 1.

24. NRC, *River Resource Management in the Grand Canyon*, note 6 above, page 16.

25. Ibid., page 17.

26. U.S. Bureau of Reclamation, note 6 above, page 11.

27. Ibid.

28. These interim flows limited daily maximum releases, minimum flows, and changes in release rates. See NRC, *River Resource Management in the Grand Canyon*, note 6 above, page 57.

29. *Grand Canyon Protection Act of 1992*, P.L. No. 102–575, 106 Stat. 4699 (1992).

30. The new flow rules were adjusted slightly from the modified low-fluctuating flow scenario described in the environmental impact statement to include a minor change in the timing of beach/habitat-building flows. See U.S. Department of the Interior, *Record of Decision: Operation of Glen Canyon Dam Final Environmental Impact Statement*, 1996.

31. GCMRC, *The Grand Canyon Monitoring and Research Center Long-Term Monitoring and Research Strategic Plan* (Flagstaff: GCMRC, 1997), 28.

32. See NRC, *Downstream: Adaptive Management of Glen Canyon Dam and the Colorado River Ecosystem*, note 6 above, pages 125–34 on institutional roles.

33. GCMRC, *Operating Protocols for Grand Canyon Monitoring and Research Center, U.S. Department of the Interior, Office of the Assistant Secretary for Water and Science* (Flagstaff: GCMRC, 1996).

34. For a discussion of these deliberations, see ibid., pages 77–79.

35. See GCMRC, *Final Report of the Physical Resources Monitoring Peer Review Panel* (Flagstaff: U.S. Geological Survey Field Center, 1999).

36. GCMRC, *Colorado River Ecosystem Science Symposium, Abstracts, February 16–17 at Grand Canyon National Park* (Flagstaff: GCMRC, 1999).

37. World Commission on Dams, *Dams and Development: A New Framework for Decision-Making*, (London and Sterling, Va.: Earthscan Publications Ltd., 2000), 2. For a review of this report, see R. E. Bissell, "A Participatory Approach to Strategic Planning, Dams and Development: A New Framework for Decision-Making" *Environment*, September 2001, 37–40.

38. World Commission on Dams, note 37 above, pages xxxiv–xxxv.

39. For more information on the 2001 GCMRC Science Symposium abstracts, see http://www.gcmrc.gov/abstract.htm.

40. See K. Arrow et al., *Report of the NOAA Panel on Contingent Valuation*, Federal Register 58, no. 10 (1993): 4601–14; T. Cameron and J. Englin, "Respondent Experience and Contingent Valuation of Environmental Goods," *Journal of Environmental Economics and Management* 33, no. 3 (1997): 296–313; and see N. Hanley, C. Spash, and L. Walker, "Problems in Valuing the Benefits of Biodiversity Protection," *Environmental and Resource Economics* 5, no. 3 (1995): 249–72.

41. See D. Harpman, E. Sparling, and T. Waddle, "A Methodology for Quantifying and Valuing the Effects of Flow Changes on a Fishery," *Water Resources Research* 29, no. 3 (March 1993): 575–82.

42. See J. March, *The Pursuit of Organizational Intelligence: Decisions and Learning in Organizations* (London: Blackwell Publishers, 1999).

43. R. Healy and W. Ascher, "Knowledge in the Policy Process: Incorporating New Environmental Information in Natural Resources Policy Making," *Policy Sciences* 28 (1995): 1–19.

44. Science-policy programs comparable to those in the Colorado River are underway in the San Juan, Green, upper Colorado, and lower Colorado River basins. The World Commission on Dams sponsored detailed case studies of eight dams around the world, including a two-volume work on cumulative impacts associated with Grand Coulee Dam in the Columbia River basin. The commission also sought to compare insights from a larger "cross-check survey" of more than 100 dams. Less formal—but no less valuable—comparisons of science-policy experiments are also underway in the Adaptive Management Practitioners' Network, accessed via http://www.iatp.org/AEAM on 24 October 2001. For an explicit comparison of river system management, see J. W. Jacobs, "Comparing River Basin Development Experiences from the Mississippi and the Mekong," *Water International* 24, no. 3 (1999): 196–203.

45. World Commission on Dams, note 37 above, page 192.

46. J. L. Wescoat Jr. and S. Halvorson, *Ex Post Evaluation of Dams and Water Related Projects: Patterns, Problems, and Promise* (Final report to the World Commission on Dams, South Africa, 2000; photocopy on file with authors).

47. For more on the Adaptive Management Practitioners' Network, see http://www.iatp.org/AEAM/index.html, last accessed on 2 January 2002.

48. See G. F. White, "The Environmental Effects of the High Dam at Aswan," *Environment*, September 1998, 5–11, 34–40.